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Chemical Characterization and Cooking Time of Cassava Roots from Different Cultivars at Four Harvesting Periods

Caracterização Química e Tempo de Cozimento das Raízes de Mandioca de Diferentes Cultivares em Quatro Épocas de Colheita

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Abstract
The object of this work was to evaluate the chemical and enzymatic parameters as well as the cooking time of cassava roots from 21 cultivars at different harvesting times. The goal was to select the best fit for each time. The roots were harvested in 11, 14, 17, and 20 months after planting. The analyses performed were done to understand the moisture content, carotenoid levels, total sugars, and HCN (hydrocyanic acid), as well as the activities of polyphenol oxidase and peroxidase enzymes, and cooking time. The HCN content and cooking time were below, respectively, 100 mg kg^{-1} and 30 minutes, classifying the cassava roots as tender and featuring cooking times that are well accepted. Regarding the total carotenoid content, with pro-vitamin A potential, the cultivar "Engana Ladrão" stood out, making its consumption particularly appealing—especially from the 11- and 14-month harvests—in regions with populations deficient in vitamin A. Based on the obtained data, producers can select the cultivar to be planted in order to achieve better outcomes in chemical, enzymatic, and culinary parameters, depending on the harvest season.

Keywords: Hydrocyanic Acid. Total Carotenoids. Manihot esculenta Crantz. Cooking Time.

Resumo
O objetivo do presente trabalho foi avaliar os parâmetros químicos, enzimáticos e o tempo de cozimento de raízes de 21 cultivares de mandioca em diferentes épocas de colheita, visando selecionar

as mais adequadas para cada época. As raízes foram colhidas em 11, 14, 17 e 20 meses após o plantio. As análises realizadas foram para conhecer os teores de umidade, carotenóides, açúcares totais e HCN (ácido cianídrico), atividades das enzimas polifenoloxidade e peroxidase e o tempo de cozimento. O teor de HCN e o tempo de cozimento foram inferiores, respectivamente a 100 mg kg-1 e 30 minutos, sendo as raízes de mandioca consideradas mansas e com tempos de cozimento que possuem boa aceitabilidade. Em relação ao teor de carotenóides totais, com potencial pró-vitamina A, o destaque foi para a cultivar "Engana Ladrão", sendo interessante o seu consumo, principalmente provenientes das colheitas de 11 e 14 meses, em regiões com população carente em vitamina A. Pelos dados obtidos, é possível, para o produtor, selecionar a cultivar a ser plantada, com vistas a obter os melhores resultados dos parâmetros químicos, enzimáticos e culinário, conforme a época de colheita.

Palavras-chave: Ácido Cianídrico. Carotenóides Totais. Manihot esculenta Crantz. Tempo de Cozimento.

1 Introduction

Cassava (Manihot esculenta Crantz) is a staple food and an important, low-cost source of carbohydrates (Niyibituronsa *et al.*, 2021). It is one of the most significant crops for human nutrition in the tropics, particularly among low-income populations (Mezette *et al.*, 2009). In addition to its role as a key industrial and food security crop, cassava contributes to livestock feed production and industrial biomass generation in Africa, Asia, and South America (Ayetigbo *et al.*, 2018). Its roots can be consumed in the form of cassava flour or starch-derived products, and they are also processed domestically and eaten boiled, fried, or used in the preparation of traditional dishes (Mezette *et al.*, 2009).

The extensive number of cassava cultivars adapted to diverse regions results in significant variation in the chemical composition of this root (Ceni *et al.*, 2009). Ceni *et al.* (2009) concluded that the chemical composition of cassava roots is specific not only to the cultivar but also depends primarily on associated genetic factors. Generally, cassava roots have a high moisture content (higher than 60%) and starch content (higher than 20%). They contain minimal amounts of proteins, vitamins, minerals, and fiber, and are deficient in essential amino acids such as methionine and tryptophan (Almeida; Ferreira Filho, 2005). Cassava roots, especially those with yellow pulp, contain carotenoids, with levels ranging from 1.02 to 10.40 μg g^{-1} of fresh tissue, indicating potential to help address vitamin A deficiency in regions where this condition is prevalent (Chávez *et al*., 2005).

Cassava cultivars are classified as sweet, typically used for human and animal consumption, and bitter, generally employed in industry for the production of flour and starch due to their usually higher HCN (hydrocyanic acid) content, rendering them unsuitable for direct consumption. The cyanogenic glycosides found in cassava roots are responsible for its toxicity (Niyibituronsa *et al.*, 2021).

Due to the high perishability of fresh cassava, it must be consumed within a short period after harvest. The main cause of loss is attributed to physiological deterioration, which is linked to the activity of peroxidase (Ramos et al., 2013) and polyphenol oxidase (Carvalho *et al*., 1985) enzymes, making the study of these enzymes activities particularly important.

An important culinary characteristic to be analyzed in cassava roots is cooking time. According to Lorenzi (1994), irregularity in the culinary quality of edible cassava roots is one of the factors limiting the expansion of their consumption. Well-cooked roots should, when mashed, form a paste that is smooth, plastic, and non-sticky. Cooking time correlates well with the quality of the cooked paste; that is, the shorter the time, the better the resulting paste.

Harvest time, in addition to the type of management, influences the technological and physicochemical quality of cassava roots, such as moisture, starch, and protein content. For instance, peeling difficulty may increase with delayed harvest (Tagliapietra *et al.*, 2021).

Due to the variation in chemical components and cooking time of cassava cultivated for direct consumption, it is worthwhile to evaluate these characteristics across different cultivars and harvest periods, with the aim of selecting the best suited cultivars for each season.

2 Material and Methods

2.1 Harvesting and preparation of the roots

The roots were provided by the Northern Minas Gerais Regional Unit (URENM) of the Empresa de Pesquisa Agropecuária de Minas Gerais (EPAMIG). The experiment, used as the local source, took place at the Mocambinho Experimental Farm (FEMO), within the Jaíba Irrigation Perimeter, Jaíba, Minas Gerais, Brazil.

Three plants from each replicate were collected at each harvest period and subsequently evaluated. The harvest periods were approximately 11, 14, 17, and 20 months.

The roots were prepared by first washing them with a brush to remove field dirt. They were then sanitized by immersion in a sodium hypochlorite solution (200 mg L^{-1}) for 15 minutes. Afterward, the roots were peeled and again sanitized by immersion in sodium hypochlorite for 15 minutes. Next, they were cut into five cm pieces and immersed in potable water to prevent discoloration, until packaged in plastic and taken to a freezer at -18 °C for subsequent analyses.

2.2 Experimental Design

The experimental design was completely randomized, consisting of 21 cultivars with three repetitions for each harvest period of the roots. The treatments were coded from T1 to T21, as shown in Table 1.

Table 1 - Code and cultivars characterized in

the present study

Code	Cultivar	Code	Cultivar
T1	Amarelinha	T11	Gema de Ovo
T2	347	T12	Dourada
T3	IAC 712	T13	266
T4	12818	T14	Paulistinha
T5	IAC 127	T15	Prato Cheio
T6	Mico	T16	IAC 1418
T7	356	T17	Cidade Rica
T8	141	T18	118
T9	Abacate	T19	361
T10	Olho Roxo	T20	Engana Ladrão
		T21	Olho Roxo Local

Source: research data.

2.3 Analyses performed on cassava roots for each harvest period

2.3.1 Moisture

The moisture content of the grated roots was determined gravimetrically by pre-drying in an oven at 65 °C, followed by drying at 105 °C until a constant mass was achieved. The results were expressed in g 100 g^{-1} (AOAC, 2000).

2.3.2 Cooking time

Cooking time was determined using a modified Mattson cooker, adapted to assess the cassava cooking (Oliveira et al., 2001). The equipment was made of stainless steel and comprised 24 pins. Calibration was performed at the top of each pin, where a 40 g capsule is screwed in.

The fresh peeled roots were cut into 3 cm sections. Using a manual vegetable slicer with a 10 mm grid, cassava sticks measuring 10 mm x 10 mm x 30 mm were cut.

In a metal container, 1 L of distilled water was boiled and then placed in the Mattson cooker along with 24 cassava sticks, which were prepared as follows: each cassava stick was positioned in one of the cavities on the lower plate of the device, beneath the tip of one of the metal pins. The cooking time was measured and determined by the moment the 13th pin dropped, piercing the cassava sample.

2.3.3 Starch

The starch was extracted by acid hydrolysis following the procedure of the Association of Official Agricultural Chemists (AOAC, 2000) and determined by the Somogy method modified by Nelson (1944). The results were expressed in g 100 g^{-1}.

2.3.4 Carotenoids

The carotenoids were determined according to the technique of Rodrigues-Amaya and Kimura (2004). A 5 g sample was weighed, 35 mL of acetone was added, and the sample was then homogenized using a sample homogenizer (Politron). The material was filtered and washed with 80 mL of acetone. The filtrate was transferred to a separation funnel along with 100 mL of distilled water and 30 mL of petroleum ether. This step was repeated three more times, without the addition of petroleum ether. The supernatant was transferred to a 50 mL volumetric flask, and the volume was completed with petroleum ether.

The total carotenoid content was determined by measuring absorbance at 450 nm and calculated using the β-carotene coefficient (A1%cm = 2592). The results were expressed in µg 100g-1.

2.3.5 Total Sugars

The total sugars were quantified using the Anton method (Dische, 1962).

2.3.6 Hydrocyanic Acid (HCN) Content

The cyanide content was determined in the root samples through qualitative phytochemical profiling and calculated as described by Haque and Bradbury (2001).

2.3.7 Polyphenol Oxidase

The polyphenol oxidase enzyme activity was determined according to the method described by Ponting and Joslyn (1948), with modifications for cassava. The enzymatic extract was obtained by homogenizing 10 g of crushed sample with 50 mL of 0.05 mol L^{-1} phosphate buffer at pH 7.0. After filtration using Whatman No. 1 filter paper, 1.0 mL of the enzymatic extract was mixed with 3.6 mL of 0.1 mol L^{-1} phosphate buffer (pH 6.0) and incubated with 0.1 mL of 10 mmol L^{-1} catechol for 30 minutes at 30 °C. The reaction was stopped by adding 1.6 mL of 2 mol L^{-1} perchloric acid. Absorbance was then measured using a spectrophotometer at a wavelength of 395 nm. The activity was expressed in U g^{-1} $minute^{-1}$.

2.3.8 Peroxidase

The peroxidase activity was determined according to the technique described by Ferhmann and Diamond (1967), with modifications for cassava, using the same enzyme extract as for polyphenol oxidase activity. For the assay, 3.0 mL of the enzyme extract, 5.0 mL of 0.2 M phosphate-citrate buffer (pH 5.0), and 0.5 mL of 3% hydrogen peroxide were incubated with 0.5 mL of guaiacol at 30 °C for 5 minutes. The reaction was stopped by adding 1.0 mL of 30% sodium bisulfite, and absorbance readings were taken using a spectrophotometer at a wavelength of 470 nm. The enzyme activity was expressed in U g^{-1} min^{-1}.

2.4 Statistical analysis

The results from each analysis for each cultivar were statistically analyzed using the Scott-Knott mean test with the Sisvar software (Ferreira, 1999).

3 Results and Discussion

3.1 Chemical characterizations and cooking time

In Table 2, the values of starch and total sugars for the 21 cassava cultivars studied across four harvest periods are presented.

Table 2 - Means of Starch Content (g 100 g-1) and Total Sugars (g 100g-1) in Four Harvests (11, 14, 17, and 20 Months) of Cassava Roots

Chemical Components	Starch (%)				Total Sugars (%)			
	Harvest				Harvest			
Cultivars	1ª	2ª	3ª	4ª	1ª	2ª	3ª	4ª
T1	15.63 d	22.05 c	22.17 c	25.15 f	2.26 c	1.88 a	2.44 b	1.44 f
T2	26.82 a	21.77 c	24.94 b	32.71 c	3.44 a	1.85 a	1.88 c	1.19 g
T3	25.43 b	18.84 c	10.15 f	16.32 h	2.47 c	1.25 b	1.78 c	1.57 e
T4	22.01 b	25.99 b	31.74 a	26.77 e	1.50 f	1.46 b	1.44 d	2.92 a
T5	23.09 b	19.77 c	31.24 a	26.85 e	3.06 b	1.45 b	2.58 a	1.71 d
T6	24.72 b	28.91 b	30.01 a	11.61 i	1.65 e	1.68 a	2.43 b	1.73 d
T7	29.22 a	30.50 b	22.08 c	29.12 d	3.57 a	1.41 b	2.68 a	1.31 f
T8	20.93 c	13.44 d	21.66 c	24.88 f	1.44 f	1.81 a	1.37 d	1.82 d
T9	22.31 b	21.73 c	32.14 a	36.63 a	1.93 d	1.48 b	2.18 b	2.64 b
T10	19.45 c	28.68 b	30.09 a	32.75 c	2.39 c	2.79 a	1.97 c	1.37 f
T11	23.84 b	27.83 b	11.21 f	29.17 d	2.31 c	1.49 a	1.81 c	1.95 d
T12	14.75 d	22.42 c	15.12 e	19.43 g	2.01 d	1.48 b	2.73 a	2.69 b
T13	17.46 d	28.21 b	32.39 a	27.30 e	1.32 f	1.87 a	2.75 a	1.51 e
T14	21.02 c	27.49 b	26.22 b	31.27 c	2.34 c	1.71 a	1.82 c	1.72 d
T15	14.48 d	35.12 a	15.95 e	27.73 e	2.42 c	1.42 b	1.16 d	2.95 a
T16	20.96 c	15.62 d	30.58 a	29.41 d	2.46 c	1.38 b	1.59 c	1.15 g
T17	23.52 b	26.13 b	28.37 b	34.62 b	2.87 b	1.71 a	1.74 c	1.52 e
T18	23.50 b	33.40 a	18.92 d	33.71 c	1.60 e	2.19 a	1.58 c	2.39 c
T19	28.70 a	20.20 c	27.39 b	29.71 d	1.67 e	1.15 b	2.48 b	1.16 g
T20	23.82 b	26.92 b	26.94 b	34.69 b	1.63 e	1.83 a	2.30 b	1.54 e
T21	20.29 c	32.88 a	29.50 a	20.47 g	1.43 f	2.76 a	1.68 c	1.56 e

The means followed by the same letter in the column do not differ significantly from each other, according to the Scott-Knott test ($p < 0.05$).
Source: research data.

Although the percentage of starch in the roots is more critical for selecting materials for industrial purposes, it is also significant in the improvement of cassava for direct consumption, since the utilization of the roots involves the production of flour and starch (Silva et al., 2014).

Regarding starch in the whole sample, the best values were 29.22 g/100 g (T7) in the first harvest; 35.12 g/100 g (T15) in the second harvest; 32.39 g/100 g (T13) in the third harvest; and 36.63 g/100 g (T9) in the fourth harvest, in accordance with studies by Sriroth et al. (2000).

Silva et al. (2014) investigated 13 cassava accessions whose starch content varied from 19.60% to 32.83%, values also similar to those obtained in the present work. Economically viable cassava roots should have a starch content higher than 20 g/100 g (Sriroth et al., 2000).

The cultivars that exhibited starch content below 20 g/100 g in three harvest periods were T3 and T12, without displaying any consistent pattern in relation to harvest time.

For total sugars, the highest values were 3.57 g glucose per 100 g (T7) at the first harvest; 2.79 g glucose per 100 g (T10) at the second harvest; 2.75 g glucose per 100 g (T13) at the third harvest; and 2.95 g glucose per 100 g (T15) at the fourth harvest.

Fenimam (2004) reported mean values lower than those observed in this experiment, approximately 2.45 g glucose per 100 g for roots harvested at 12 months and 1.65 g glucose per 100 g for roots harvested at 15 months. In general, there was a decrease in the total sugar content with increasing root age in this experiment.

This trend can be explained by the plant's developmental cycle, which comprises five physiological phases during which the plant requires more energy in its early stages.

Cultivars with higher sugar content tend to have a sweeter flavor and are preferred in sensory evaluations (Miya et al., 1975); thus, higher total sugar values - specifically glucose and sucrose - are desirable in cassava roots, making a shorter harvest time generally preferable.

Table 3 shows the values of carotenoids and hydrocyanic acid for the 21 cultivars studied in four harvests

Table 3 - Values of carotenoids and hydrocyanic acid for the 21 cultivars in four harvests

Chemical Compounds	**Carotenoids (µg 100g^{-1})**				**HCN (hydrocyanic acid) (mg HCN eq. kg^{-1})**			
Harvest/ Cultivar	1st	2nd	3rd	4th	1st	2nd	3rd	4th
T1	230.56 j	144.18 m	132.20 h	66.28 p	8.76 e	16.15 g	9.03 d	4.74 c
T2	133.86 o	173.35 i	184.00 d	57.68 q	7.10 c	22.24 i	7.79 c	6.01 d
T3	479.63 b	175.54 h	128.79 i	181.46 c	7.55 d	12.32 e	7.69 c	3.26 a
T4	120.43 q	69.56 s	65.40 n	85.38 n	8.29 d	9.64 l	12.83 f	5.31 c
T5	191.57 l	108.71 q	115.04 l	183.38 c	8.86 e	3.05 a	9.96 e	4.00 b
T6	350.44 e	168.67 j	176.42 e	210.13 b	6.03 b	25.36 j	10.98 e	4.15 b
T7	131.94 p	154.30 l	215.46 b	147.52 f	7.04 c	12.62 e	10.66 e	6.31 d
T8	163.23 m	203.80 d	122.33 j	171.56 d	8.11 d	17.03 g	6.03 b	7.38 e
T9	249.54 i	136.95 n	128.91 i	161.55 e	8.34 d	10.52 d	6.55 b	8.81 f
T10	160.67 n	182.73 g	117.61 l	135.80 g	8.57 e	9.35 c	7.62 c	7.20 e
T11	118.65 q	137.10 n	92.51 m	108.40 i	7.08 c	10.69 d	14.07 g	2.71 a
T12	340.19 f	457.97 b	52.10 o	47.08 r	6.05 b	13.69 f	9.09 d	4.52 b
T13	135.49 o	117.24 p	43.58 p	31.67 s	12.48 h	11.65 e	8.75 d	5.14 c
T14	91.11 r	103.79 r	127.07 i	86.61 n	6.93 c	2.27 a	5.94 b	7.76 e
T15	290.77 g	131.73 o	183.85 d	97.06 l	10.99 g	22.60 i	11.39 e	4.66 c
T16	397.07d	173.16 i	174.77 e	103.64 j	11.00 g	17.98 h	17.18 h	4.82 c
T17	130.85 p	187.32 f	138.30 g	116.82 h	9.88 f	11.04 d	8.61 d	6.17 d
T18	450.88 c	267.56 c	206.90 c	147.54 f	8.86 e	11.03 d	10.33 e	4.50 b
T19	258.51 h	189.36 e	115.83 l	68.98 o	8.76 e	22.27 i	7.30 c	7.51 e
T20	582.36 a	612.14 a	366.67 a	231.25 a	3.57 a	5.31 b	6.06 b	8.62 f
T21	190.51 l	144.72 m	168.33 f	94.44 m	6.15 b	8.07 c	4.73 a	3.37 a

Means followed by the same letter in the column do not differ significantly from each other, as determined by the Scott-Knott test ($P < 0.05$).
Source: research data.

People in vast areas of the tropics suffer from vitamin A deficiency, which results in progressive eye damage and can eventually lead to blindness. Enhancing the content of vitamin A precursors, such as β-carotene, in staple crops could help mitigate or even resolve this problem (Iglesias *et al.,* 1997). Therefore, it is important to determine the levels of total carotenoids and to identify any patterns related to harvest time in cassava cultivars, to promote greater utilization of roots with higher levels of provitamin A.

For total carotenoids, the highest values were 582.36 µg/100 g at the first harvest; 612.14 µg/100 g at the second harvest; 366.67 µg/100 g at the third harvest; and 231.25 µg/100 g at the fourth harvest. The highest values for each harvest were obtained for the cultivar Engana Ladrão (T20). These levels fall within the range reported by Mezette et al. (2009), which varied from 329.5 to 1,108.1 µg/100 g.

Both cassava cultivars studied by Odoemelam *et al.* (2020) had carotenoid contents of 653 µg/100 g and 117 µg/100 g, values that were also observed in this work. In the same study, cassava roots were used for food production, and the retention of β-carotenoids in the final products was subsequently assessed.

The cake produced retained a residual β-carotene concentration of 284 μg/100 g, whereas the cookie retained 215 μg/100 g. This study demonstrates that the Engana Ladrão (T20) cultivar has the greatest potential for use as a raw material in the production of foods such as cakes and cookies.

It was observed in this experiment that the maximum carotenoid levels generally decrease as the roots age. Therefore, for cultivar T20, which stood out in the present experiment, the ideal harvest times for consumption, considering higher carotenoid contents, are 11 and 14 months.

In terms of HCN content, the lowest levels were 3.57 mg HCN eq. per kg (T20) at the first harvest; 2.27 mg HCN eq. per kg (T14) at the second harvest; 4.73 mg HCN eq. per kg (T21) at the third harvest; and 2.71 mg HCN eq. per kg (T11) at the fourth harvest.

These results are like those reported by Udoro et al. (2020), who found values of 3.62 mg kg^{-1} and 3.51 mg kg^{-1} for red and white roots, respectively. However, these values are lower than those found by Lorenzi and Dias (1993), who evaluated 206 cassava genotypes intended for domestic consumption in the domestic plots of São Paulo, Brazil, and observed that only 24.8% of the cultivars had up to 50 mg HCN eq. per kg in the raw root pulp.

This finding is consistent with Normanha and Pereira (1956) and Pereira, Lorenzi, and Abramides (1977), who stated that the safety limit for cassava consumption should be 100 mg HCN eq. per kg of raw root pulp, ensuring that the cultivation and consumption of these cultivars are safe for the population.

This safety limit, suggested by the Campinas Agronomic Institute of the São Paulo State Department of Agriculture, has since been widely adopted in Brazil. Therefore, all the cultivars in this experiment can be classified as "soft" or table cassava, as they exhibit HCN levels below 100 mg kg^{-1}.

Table 4 shows the values found in the cassava cultivars studied, the levels of the enzymes polyphenol oxidase and peroxidase at the four different harvest times.

Table 4 - Values found for the levels of polyphenol oxidase and peroxidase enzymes

Enzymes	**Polyphenol oxidase ($U\ g^{-1}\ minute^{-1}$)**				**Peroxidase ($U\ g^{-1}\ minute^{-1}$)**			
Harvest/ Cultivar	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**
T1	67.14 h	46.70 c	57.23 g	72.55 f	171.96 e	171.48 e	208.67 e	246.44 e
T2	44.83 a	45.27 c	64.84 i	81.08 g	131.17 b	141.44 c	161.49 b	222.90 c
T3	47.68 b	45.16 c	31.44 a	83.00 h	161.70 d	159.43 e	176.82 c	250.69 e
T4	57.77 e	57.59 e	47.53 d	104.08 j	211.22 h	290.15 i	206.01 e	220.98 c
T5	81.74 i	46.76 c	58.18 g	83.12 h	298.12 l	183.59 f	239.33 f	307.19 g
T6	45.78 a	38.06 b	53.53 f	51.32 b	184.32 f	154.36 d	214.29 e	237.10 d
T7	89.40 j	56.49 e	42.86 c	62.34 d	347.86 n	226.03 h	204.47 e	256.01 e
T8	42.93 a	47.92 d	37.95 b	63.81 d	150.15 c	146.66 c	153.64 b	224.16 c
T9	56.32 e	45.18 c	57.97 g	65.12 d	190.45 f	152.82 d	210.21 e	199.16 b
T10	64.04 g	49.44 d	60.82 h	118.76 m	248.90 i	200.84 g	194.31 d	311.24 g
T11	61.31 f	37.18 b	38.14 b	80.24 g	202.02 g	142.81 c	156.08 b	181.86 a
T12	55.03 d	32.69 a	49.56 e	55.97 c	198.51 g	103.043 a	168.59 c	220.18 c
T13	69.58 h	37.23 b	37.31 b	55.92 c	247.52 i	168.34 e	126.18 a	231.90 d
T14	63.37 g	49.80 d	41.29 c	79.27 g	202.65 g	189.96 f	172.97 c	260.46 e
T15	48.97 b	53.52 e	52.82 f	77.93 g	112.52 a	183.27 f	176.35 c	250.19 e
T16	51.41 c	48.21 d	47.01 d	102.05 j	187.26 f	166.72 e	198.62 d	340.84 h
T17	57.48 e	44.22 c	60.68 h	50.90 b	270.71 j	118.053 b	175.71 c	195.30 b
T18	102.87 l	88.13 f	52.85 f	67.69 e	328.17 m	139.59 c	171.19 c	255.46 e
T19	48.74 b	44.71 c	53.13 f	85.83 i	177.35 e	194.67 g	160.03 b	299.35 g
T20	64.03 g	49.12 d	66.23 i	115.46 l	219.01 h	283.97 i	309.85 g	281.90 f
T21	52.51 c	39.39 b	36.49 b	39.66 a	169.75 e	124.18 b	213.42 e	174.55 a

Means followed by the same letter in the column do not differ significantly from each other, as determined by the Scott-Knott test ($P < 0.05$).
Source: resarch data.

Physiological deterioration has been closely linked to oxidative changes in phenolic substances and to the enzymes involved in their oxidation, such as peroxidase and polyphenol oxidase (Carvalho *et al.,* 1985). Therefore, it is important to measure the activity of these enzymes in Cassava cultivars, with lower activity levels being desirable. In general, the activities of both enzymes increased from the first to the fourth harvest period, suggesting that cultivars with shorter harvest intervals may be preferable.

For the lowest polyphenol oxidase activities, the values ranged from 42.93 $U\ g^{-1}\ min^{-1}$ (T8) at the first harvest; 32.69 $U\ g^{-1}\ min^{-1}$ (T12) at the second harvest; 31.44 $U\ g^{-1}\ min^{-1}$ (T3) at the third harvest; and 39.66 $U\ g^{-1}\ min^{-1}$ (T21) at the fourth harvest. These results are like those reported by Coelho (1992), who, when evaluating different harvest ages of three cassava cultivars, found that the activity of this enzyme varied from 17 to 75 $U\ g^{-1}\ min^{-1}$.

In the peroxidase analysis, the lowest activities recorded were 112.52 $U\ g^{-1}\ min^{-1}$ at the first harvest; 103.04 $U\ g^{-1}\ min^{-1}$ at the second harvest; 126.18 $U\ g^{-1}\ min^{-1}$ at the third harvest; and 178.21 $U\ g^{-1}\ min^{-1}$ at the fourth harvest. These results were higher than those reported by Bezerra et al. (2002), who found peroxidase activity of 49.89 $U\ g^{-1}\ min^{-1}$ in the roots of the Baianinha cultivar. This increase in peroxidase activity may be attributed to the stress the roots experienced from harvest until processing for analysis, such as exposure to sunlight and oxygen, ambient temperature (without refrigeration), and the inherent stress of the harvest itself over a period exceeding 24 hours.

Table 5 shows the moisture and cooking time values for the cassava cultivars studied (in four harvest seasons).

Table 5 - Moisture content and cooking time values for the Cassava cultivars

		Moisture (g 100g^{-1})			Cooking Time (Minutes)			
Harvest/ Cultivar	**1st**	**2nd**	**3rd**	**4th**	**1st**	**2nd**	**3rd**	**4th**
T1	81,88 e	71,66 b	75,06 d	67,52 e	15,66 b	13,66 b	14,33 b	17,66 e
T2	69,92 a	75,87 c	71,24 b	64,32 c	13,66 a	13,00 a	14,00 a	21,66 g
T3	67,95 a	78,75 d	80,46 e	79,73 h	14,66 b	14,00 b	14,67 b	13,66 b
T4	71,02 b	69,81 b	64,59 a	69,58 f	15,33 b	14,66 b	13,33 a	16,00 c
T5	74,39 c	72,70 c	64,53 a	64,34 c	13,33 a	14,00 b	16,33 c	13,66 b
T6	68,53 a	65,82 b	66,84 a	83,81 i	16,00 b	14,00 b	14,00 a	13,66 b
T7	66,75 a	65,16 a	70,39 b	67,90 e	16,66 b	13,66 b	13,33 a	17,33 e
T8	72,43 b	82,30 d	72,25 c	70,67 f	14,66 b	13,33 a	13,66 a	14,00 b
T9	74,16 c	68,27 b	62,69 a	58,45 a	18,66c	12,33 a	13,66 a	17,66 e
T10	77,88 d	67,41 b	65,00 a	61,99 b	22,00 e	12,33 a	13,33 a	12,66 a
T11	71,18 b	69,15 b	81,50 e	67,08 e	15,66 b	14,33 b	13,66 a	13,66 b
T12	82,30 e	74,68 c	76,03 d	76,91 g	15,66 b	15,33 c	16,67 c	13,66 b
T13	76,65 d	67,13 b	62,87 a	69,30 f	18,00 c	14,00 b	16,33 c	14,33 b
T14	71,27 b	67,59 b	67,32 b	64,44 c	15,66 b	12,66 a	13,66 a	15,33 c
T15	80,54 e	60,40 a	78,76 e	67,87 e	13,33 a	15,66 c	17,67 d	13,66 b
T16	75,34 d	81,33 d	62,98 a	66,20 d	14,33 a	13,00 a	15,67 c	15,66 c
T17	72,01 b	69,90 b	66,06 a	59,59 a	15,33 b	13,66 b	15,67 c	14,33 b
T18	71,62 b	62,87 a	68,21 b	60,51 b	15,33 b	12,33 a	14,67 b	12,66 a
T19	67,51 a	74,38 c	69,54 b	65,98 d	20,00 d	21,00 d	18,67 e	18,66 f
T20	71,40 b	69,88 b	65,25 a	59,78 a	15,00 b	14,33 b	16,00 c	15,66 c
T21	74,68 c	60,75 a	66,55 a	76,58 g	13,33 a	12,00 a	17,67 d	16,33 d

Means followed by the same letter in the column do not differ significantly from each other, as determined by the Scott-Knott test ($P < 0.05$).
Source: resarch data.

For the moisture analysis, the lowest values were 66.75 g per 100 g (T7) at the first harvest; 60.40 g per 100 g (T15) at the second; 64.53 g per 100 g (T5) at the third; and 58.45 g per 100 g (T9) at the fourth harvest, which are close to the results obtained by Fenimam (2004) of 66.86 g per 100 g.

Padonou, Mestres, and Nago (2005), evaluating the composition of 20 cassava cultivars, found that their moisture content varied from 60.3 g per 100 g to 80.9 g per 100 g, while Grizotto and Menezes (2003) assessed the proximate composition of the IAC Mantiqueira and IAC 576,70 cultivars and observed moisture values ranging from 57.6 to 58.2 g per 100 g. These differences in the roots moisture content may stem from variations in the amount of water available in the soil and the plant’s vegetative stage.

There was no consistent pattern between moisture content and harvest time, as observed in the values of Table 5.

The water content is one of the most important factors in root preservation due to its direct influence on their shelf life, as cultivars resistant to physiological deterioration exhibit higher moisture contents (Carvalho et al., 1982).

The cooking of cassava roots is very important for ensuring good consumer acceptance of the product (Cereda; Vilpoux, 2025). Consumers prefer cassava roots that cook quickly during boiling (Tran et al., 2021), which underscores the importance of knowing the cooking time for each cultivar studied.

The lowest cooking times for the cultivars were as follows: 13.33 min (T5 and T21) at the first harvest; 12 min (T21) at the second harvest; 13.33 min (T4, T7, and T10) at the third harvest; and 12.66 min (T10 and T18) at the fourth harvest. Generally, cooking times of less than 30 minutes are considered indicative of good culinary quality (Freitas Fialho et al., 2009). Valle et al. (2007) states that, under optimal conditions, cooking is achieved in 15 minutes.

According to Lorenzi (1994), soil type can prolong cooking time; less fertile soils produce roots with longer cooking times or even roots that do not cook properly. However, the composition and characteristics of the species itself cause natural variation in cooking time, both within the same root and among roots of the same plant (Lorenzi, 2003). This explanation justifies the differences in cooking times among the studied cultivars.

Fenimam (2004) reports that the roots cooking time is a concern for both consumers and the industry, as it ensures proper cooking and establishes parameters in processes that control the quality and uniformity of the final product. Cooking time is closely related to the quality of the cooked dough; in other words, the shorter the cooking time, the better the resulting dough—that is, a high-quality cassava root, once boiled and mashed with a fork, yields a non-sticky, highly pliable, lump-free dough (Lorenzi, 1994). All cultivars, regardless of harvest time, exhibited cooking times generally acceptable to consumers.

Regarding harvest time and cooking time, no consistent pattern was observed, as some cultivars exhibited an increase in cooking time while others decreased.

3.2 Cultivars with the best values for the characterizations performed

Table 6 presents the best cultivars for each analysis performed.

Table 6 - Treatments with the best values regarding the analyzed parameters: moisture (U), cooking time (TC), starch (Am), total carotenoids (CT), hydrocyanic acid (HCN), total sugars (AT), polyphenol oxidase (PFO), and peroxidase (PER) in each harvest period (EC), according to the Scott-Knott test at 5% significance

EC	U*1	TC*1	Am*2	CT*2	HCN*1	AT*2	PFO*1	PER*1
1	T2, T3, T6, T7, T19	T2, T5, T15, T16, T21	T2,T7, T19	T20	T20	T2, T7	T2, T6, T8	T15
2	T7, T15, T18, T21	T2, T8, T9, T10, T14, T16, T18, T21	T15, T18, T21	T20	T5, 14	T10, T21	T12	T12
3	T10, T13, T16, T17, T20, T21	T2, T4, T6, T7, T8, T9, T10, T11, T14	T4, T5, T6,T9, T10, T13, T16, T21	T20	T21	T5, T7, T12,T13	T3	T13
4	T9, T17, T20	T10, T18	T9	T20	T3, T11, T21	T4, T15	T21	T11, T21

HCN (Hydrocyanic Acid), PFO (Polyphenoloxidase), PER (Peroxidase), U (Moisture), TC (Cooking Time), Am (Starch), CT (Total Carotenoids), Vit C (Vitamin C), AT (Total Sugars), SST (Total Soluble Solids). EP = Harvest Period
*2 Larger values were considered optimal or the best values
*1 Smaller values were considered optimal or the best values.
Source: research data.

In terms of moisture content, lower levels are considered preferable because the roots will have a higher dry matter content and, consequently, a higher yield, whether for direct consumption or to produce flours and starch. Cultivars T7, T17, T19, T20, and T21 stood out with lower values in two harvests.

Regarding culinary aspects, cooking time is a fundamental criterion. In general, the shorter the cooking time, the higher the acceptance. In this case, cultivar T2 is notable, as it is in the group with the lowest cooking times, except for the fourth harvest.

Higher starch content potentially leads to a greater roots yield in industrial products. Cultivars T9 and T21 stood out in two harvest periods.

For total carotenoid content, with its potential as a provitamin A source, cultivar T20 is the most noteworthy, making its consumption particularly interesting, especially in regions with populations deficient in vitamin A. Due to the decrease in carotenoid content with increasing harvest time, the highest values were observed in the first and second harvests for cultivar T20.

HCN content was low for all the cultivars, classifying them as table (or "sweet") cassava, so all of them performed well in this parameter.

A higher total sugar content may be desirable for Cassava roots, as it increases consumer acceptance due to a sweeter taste (Miya *et al.*, 1975). Cultivar T7 stood out in two harvest periods.

Lower activities of the enzymes polyphenoloxidase and peroxidase are desirable since they are related to the roots physiological deterioration. Cultivars T12 and T21 stood out with lower enzyme activity values in the harvests that occurred between 14 and 20 months after planting, respectively.

4 Conclusion

Regarding the parameters analyzed in the four harvests of cassava roots, it can be concluded that the HCN content is well below the safety limit for cassava consumption, making these cultivars safe for public consumption. The lowest values were observed in the IAC 127 and Paulistinha cultivars during the second harvest.

Regarding starch, high levels were observed at all harvest periods, with the Abacate cultivar exhibiting the highest starch content in the whole sample at the fourth harvest.

The highest total carotenoid concentrations were observed in the Engana Ladrão cultivar. Generally, carotenoid concentrations decrease as the harvest time increases.

The cooking time of cassava roots is less than 30 minutes, which is considered optimal for both consumers and industry. The shortest cooking times occurred in the second harvest for the cultivars 347, 141, Abacate, Olho Roxo, Paulistinha, IAC 1418, 118, and Olho Roxo Local.

Based on the data obtained, it is possible for the producer to select the cultivar to be planted, to achieve better results for the chemical, enzymatic, and culinary parameters, according to the harvest time.

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